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FENDL/E-2.0**Evaluated nuclear data library of neutron-nucleus interaction
cross sections and photon production cross sections and
photon-atom interaction cross sections
for fusion applications**

Version 1, March 1997

Summary documentation

by

A.B. Pashchenko and H. Wienke

Abstract: This document presents the description of a physical tape containing the basic evaluated nuclear data library of neutron-nucleus interaction cross sections, photon production cross sections and photon-atom interaction cross sections for fusion applications. It is part of the evaluated nuclear data library for fusion applications FENDL-2. The data are available cost-free from the Nuclear Data Section upon request. The data can also be retrieved by the user via online access through international computer networks.

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaea.nds.iaea.or.at
fax: (43-1) 20607
cable: INATOM VIENNA
telex: 1-12645
telephone: (43-1) 2060-21710

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Online: TELNET or FTP: iaea.nds.iaea.or.at
username: IAEANDS for interactive Nuclear Data Information System
usernames: ANONYMOUS for FTP file transfer,
FENDL2 for FTP file transfer of FENDL-2.0;
RIPL for FTP file transfer of RIPL
Web: <http://www-nds.iaea.or.at>

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Note:

The IAEA-NDS-reports should not be considered as formal publications. When a nuclear data library is sent out by the IAEA Nuclear Data Section, it will be accompanied by an IAEA-NDS-report which should give the data user all necessary documentation on contents, format and origin of the data library.

IAEA-NDS-reports are updated whenever there is additional information of relevance to the users of the data library.

For citations care should be taken that credit is given to the author of the data library and/or to the data center which issued the data library. The editor of the IAEA-NDS-report is usually not the author of the data library.

Neither the originator of the data libraries nor the IAEA assume any liability for their correctness or for any damages resulting from their use.

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FENDL/E-2.0

Evaluated nuclear data library of neutron nuclear
interaction cross sections, photon production cross sections
and photon-atom interaction cross sections
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Summary

The library FENDL/E-2.0, version 1 of March 1997, contains selected evaluated neutron, photon-atom, and photon production cross sections, in ENDF format, with resonance parameters where appropriate, for 57 nuclides of importance for coupled neutron-photon transport calculations for fusion reactor design. The energy ranges from 10^{-5} eV up to 20 MeV. The library has been developed from the previous version FENDL/E-1.1 [Ref. 1] by including thirteen replacing evaluations and six for additional materials. The new evaluations were selected by the FENDL/E-2.0 selection committee [Refs. 2,3], according to the procedure agreed upon at the IAEA Advisory Group Meeting on "Completion of FENDL-1 and Start of FENDL-2", Del Mar, California, USA, 5-9 Dec. 1995 [Ref. 4], from candidate evaluations submitted by five national projects viz. JENDL-FF (Japan), BROND (Russia), EFF (European Union), ENDF/B-VI (USA) and CENDL (China).

The neutron-nucleus interaction and photon production cross sections have been selected from the following evaluated nuclear data libraries:

- BROND-2: BROND library version 2 contributed by the Russian Federation, see document IAEA-NDS-90 Rev. 8. [Ref. 5]
- ENDF/B-VI.x: ENDF/B library version VI, revision x contributed by the U.S.A., see document IAEA-NDS-100 Rev. 6. [Ref. 6]. Note that revision x is the revision number of the given material, not of the library.
- JENDL-3.1: JENDL library version 3.1 contributed by Japan, see document IAEA-NDS-110 Rev. 4. [Ref. 7].
- JENDL-FF: JENDL Fusion file contributed by Japan [Ref. 8].
- EFF-3: European Fusion library version 3 contributed by the European Community [Ref. 9].

BROND-2, ENDF/B-VI, JENDL-FF and EFF-3 are in ENDF-6 format, see document IAEA-NDS-76 Rev. 4. [Ref. 10], JENDL-3.1 is in ENDF-5 format, see document IAEA-NDS-75, Rev.1 [Ref. 11]. The FENDL/E-1.0 Evaluations for photon-atom interaction are all taken from ENDF/B-VI photon-atom interaction Library, see report IAEA-NDS-58 Rev.2 [Ref. 12].

The preliminary selection of evaluations for inclusion in FENDL/E-2.0 was made at the IAEA Consultant's Meeting on "Selection of Basic Evaluations for the FENDL-2 Library", held at Karlsruhe, Germany, June 24-28, 1996 [Ref. 3]. This preliminary selection was established by applying the following criteria [Refs. 3,4,13]:

- Presence of gamma ray production cross sections and spectra
- Correlated energy-angle neutron and charged particle emission data (MF=6).
- Recoil distributions in MF=6 format for major structural materials (recommended for other materials).
- Energy balance better than 2% at all energies.
- MF=1 descriptive information.
- Presence of uncertainty information.
- Use of Standard Reference Data such as IRDF-90.2 dosimetry cross sections in candidate files highly recommended.

For the final adoption of the pre-selected evaluations several actions, requested at the last mentioned meeting, were completed by the contributing parties. Based upon the results of these actions the final adoption was made at the IAEA Advisory Group Meeting on "Extension and Improvement of the FENDL Library for Fusion Applications (FENDL-2)", held in Vienna, March 3-7, 1997 [Ref. 14]. At this meeting it was agreed to include in the basic library FENDL/E-2.0 also the ENDF/B-6 evaluations for $^3,^4\text{He}$ and ^{197}Au . These have not been reviewed for FENDL but are contained in the current processed libraries as their need was recognized since the materials are used in fusion applications. Also the JENDL-3 evaluation for $^{\text{nat}}\text{Ga}$ was included as this material is used as a coolant in fusion reactors. The selected evaluation does not satisfy the criteria setup for FENDL evaluations (no g-production data) but is the only available data file.

Table 1 lists the materials included in FENDL/E-2.0.

The data are available from the IAEA Nuclear Data Section in ftp subdirectory "UD7: [FENDL2.TRANSPORT.FENDLE]". This subdirectory has a total size of about 51.4 Megabytes and includes 57 plus a file named "aareadme_trae.txt" containing the information presented in this summary. The nuclear data files for each of the isotopes/elements have been identified individually with names such as:

"H002BR2.DAT" for the data of H-2 from BROND-2,
 "SI030E6.DAT" for the data of Si-30 from ENDF/B-VI,
 "MO000JFF.DAT" for the data of Mo-nat from JENDL-FF,
 "FE056EFF3.DAT" for the data of Fe-56 from EFF-3
 "TA181J3.DAT" for the data of Ta-181 from JENDL-3.1

The atomic number is always written with three digits, starting with a '0' when it is smaller than 100 and '00' when smaller than 10.

All the photon-atom interaction cross section data are available in one single file named "FENDLEP.dat". A list of FENDL/E-2.0 evaluations for neutron interaction and photon production cross sections is presented in Appendix A and that of evaluations for photon-atom interactions in Appendix B.

Table 1: Materials included in FENDL/E-2.0

Neutron interaction cross sections for the isotopes:

ENDF/B-VI: ^1H , ^3H , ^3He , ^4He , ^6Li , ^7Li , ^{10}B , ^{11}B , ^{19}F , $^{28-30}\text{Si}$, ^{31}P , S , Cl , K ,
 V , $^{50,52-54}\text{Cr}$, ^{55}Mn , $^{54,57,58}\text{Fe}$, ^{59}Co , $^{58,60-62,64}\text{Ni}$, $^{63,65}\text{Cu}$, ^{197}Au , $^{206-208}\text{Pb}$

JENDL-3: ^{23}Na , Mg , Ca , Ti , ^{55}Mn , Ga , ^{181}Ta , ^{209}Bi

BROND-2: ^2H , ^{15}N , Sn

JENDL-FF: ^9Be , ^{12}C , ^{14}N , ^{16}O , ^{51}V , Zr , ^{93}Nb , Mo , W

EFF-3: ^{27}Al , ^{56}Fe

Photon-atom interaction cross sections for the elements:

ENDF/B-VI: H , He , Li , Be , B , C , N , O , F , Na , Mg , Al , Si , P , S , Cl , K , Ca ,
 Ti , V , Cr , Mn , Fe , Co , Ni , Cu , Ga , Zr , Nb , Mo , Sn , Ba , Ta , W ,
 Au , Pb , Bi .

As was agreed at the Del Mar-95 AGM the contributors of the new evaluations also provided to the NDS the processed cross section data which were derived from the these evaluations with the nuclear data processing code NJOY [Ref. 15]. The processed cross sections were in pointwise ACE format, for use with the Monte Carlo transport code MCNP4A [Ref. 16], and in the multigroup GENDF and MATXS formats, for use in coupled neutron-photon transport calculations with discrete-ordinates codes like ANISN, ONEDANT, etc, to be included in the working sublibraries FENDL/MC-2.0 and FENDL/MG-2.0 [Ref. 17] respectively.

These processed contributions, however, were primarily generated for the purpose of benchmark analysis and, as was found upon closer inspection at IAEA/NDS, the specifications for processing, used by the various contributing parties, were not uniform. Therefore and also in view of the improvements and new options incorporated in the most recent version of NJOY94, it was agreed, at the Vienna-97 Advisory Group Meeting, that all evaluations, including those carried over from FENDL/E-1.0, should be reprocessed, using NJOY94 version 61 and later versions. Each party should process their own selected evaluations and the processed multigroup and ACE data files should be submitted to IAEA/NDS by October 1, 1997. Quality assurance tests will be performed by J. White, RSIC, ORNL, USA, and results submitted to IAEA/NDS by November 30.

References

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2. IAEA Consultants' Meeting on "Selection of Basic Evaluations for the FENDL-2 Library", Karlsruhe, Germany, June 1996; summary report prepared by A.B. Pashchenko and published as report INDC(NDS)-356, September 1996

3. IAEA Advisory Group Meeting on "Extension and Improvement of the FENDL Library for Fusion Applications (FENDL-2)", summary report to be published
 4. IAEA Advisory Group Meeting on "Completion of FENDL-1 and Start of FENDL-2", Del Mar, California, USA, 5-9 December 1995, summary report prepared by A.B. Pashchenko and published as report INDC(NDS)-352, March 1996
 5. V.N. Manokhin et al., "BROND-2.2 Russian Evaluated Neutron Reaction Data Library Summary documentation, H.D. Lemmel and P.K. McLaughlin, IAEA-NDS-90 Rev. 8 (January 1994)
 6. P.F. Rose (Editor), "ENDF-6 Summary Documentation", 4th Edition of BNL-NCS-17541 (=ENDF-201) (October 1991), U.S. National Nuclear Data Center, Brookhaven National Laboratory, Upton, N.Y., USA. The IAEA documentation is presented in "ENDF-6 The U.S. Evaluated Nuclear data Library for Neutron Reaction Data by the U.S. National Nuclear Data Center including revisions up to June 1993", IAEA-NDS-100, Rev. 6 (June 1995)
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 10. P.F. Rose and C.L. Dunford, ENDF-102, "Data Formats and Procedures for the Evaluated Nuclear Data File ENDF-6", U.S. National Nuclear Data Center, Brookhaven National Laboratory, Upton, N.Y., USA, BNL-NCS-44945(October 1991). The IAEA documentation is presented in "ENDF-6 Formats Manual", IAEA-NDS-76, Rev. 4 (January 1992)
 11. R. Kinsey and B.A. Magurno, "ENDF-5 Formats Manual", (1984), IAEA Nuclear Data Services documentation, IAEA-NDS-75, Rev. 1 (September 1986)
 12. "EN6-PHOTO and JEF-2/PHOTO Photo-atomic Interaction Data Library" by the Lawrence Livermore National Laboratory, USA. Summary documentation by H.D. Lemmel, report IAEA-NDS-58, Rev. 4, (International Atomic Energy Agency, Sept. 1994)
 13. S. Ganesan (Compiler), "Improved Evaluations and Integral Data Testing for FENDL", Summary report of an IAEA Advisory Group Meeting held at Garching near Munich, Germany, September 1994, report INDC(NDS)-312 (December 1994)
- S. Ganesan (Compiler), "Review of Uncertainty Files and Improved Multigroup Cross Section Files for FENDL", summary report of an IAEA Advisory Group Meeting held in cooperation with the Japan Atomic Energy Research Institute, Tokai Research Establishment, JAERI, Japan, 8-12 November 1993, report INDC(NDS)-297 (January 1994)
14. IAEA AGM on "Extension and Improvement of the FENDL Library for Fusion Applications", IAEA headquarters, Vienna, 3-7 March 1997, summary report by A. B. Pashchenko and M. Herman and published as INDC(NDS)-372, 1997

15. R.E. MacFarlane and D. M. Muir, "The NJOY Nuclear Data Processing System, Version 91", Los Alamos National Laboratory report LA-12740-M (1994)
16. Judith F. Briesmeister, Ed, "MCNP-A General Monte Carlo N-Particle Transport Code,Version 4A", Los Alamos National Laboratory report LA-12625-M (1993)
17. "FENDL/MG-2.0 and FENDL/MC-2.0, The processed cross-section libraries for neutron-photon transport calculations, version 1". Summary documentation M. Herman and H. Wienke, report IAEA-NDS-176 Rev. 0, to be published

List of FENDL/E-2.0 Evaluations for neutron interaction
and photon production

Appendix A

MATERIAL	LIBRARY	MAT Number	File name in online system	Number of records
H-1	ENDF/B-VI.1	125	H001E6.DAT	2117
H-2 ¹	BROND-2.1	102	H002BR.DAT	496
H-3	ENDF/B-VI.0	131	H003E6.DAT	732
He-3	ENDF/B-VI.1	225	HE003E6.DAT	455
He-4	ENDF/B-VI.0	228	HE004E6.DAT	373
Li-6	ENDF/B-VI.1	325	LI006E6.DAT	2621
Li-7	ENDF/B-VI.0	328	LI007E6.DAT	4945
Be-9	JENDL-FF	425	BE009JFF.DAT	17230
B-10	ENDF/B-VI.1	525	B010E6.DAT	4594
B-11	ENDF/B-VI.0	528	B011E6.DAT	8531
C-12 ²	JENDL-FF	625	C012JFF.DAT	2613
N-14	JENDL-FF	725	N014JFF.DAT	8780
N-15	BROND-2.1	720	N015BR.DAT	4917
F-19	ENDF/B-VI.0	925	F019E6.DAT	9485
Na-23	JENDL-3.1	3111	NA023J3.DAT	4711
Mg-nat	JENDL-3.1	3120	MG000J3.DAT	4254
Al-27	EFF-3	3131	AL027EFF3.DAT	13183
Si-28	ENDF/B-6.5	1425	SI028E6.DAT	10241
Si-29	ENDF/B-6.5	1428	SI029E6.DAT	9685
Si-30	ENDF/B-6.5	1431	SI030E6.DAT	6777
P-31	ENDF/B-VI.0	1525	P031E6.DAT	848
S-nat	ENDF/B-VI.0	1600	S000E6.DAT	4594
Cl-nat	ENDF/B-VI.0	1700	CL000E6.DAT	4269
K-nat	ENDF/B-VI.0	1900	K000E6.DAT	3727
Ca-nat	JENDL-3.1	3200	CA000J3.DAT	5260
Ti-nat	JENDL-3.1	3220	TI000J3.DAT	5243
V-51	JENDL-FF	2328	V051JFF.DAT	9194
Cr-50	ENDF/B-VI.1	2425	CR050E6.DAT	6807
Cr-52	ENDF/B-VI.1	2431	CR052E6.DAT	8492
Cr-53	ENDF/B-VI.1	2434	CR053E6.DAT	8520

¹ File-6 data from JENDL-FF

² Evaluation contains contributions from ¹³C (small resonance in elastic and total cross section). This scattering cross section in the low energy range has been adopted from ENDF/B-VI.

MATERIAL	LIBRARY	MAT Number	File name in online system	Number of records
Cr-54	ENDF/B-VI.1	2437	CR054E6.DAT	5513
Mn-55	ENDF/B-VI.0	2525	MN055E6.DAT	17970
Fe-54	ENDF/B-VI.1	2625	FE054E6.DAT	7992
Fe-56	EFF-3	2631	FE056EFF3.DAT	62212
Fe-57	ENDF/B-VI.1	2634	FE057E6.DAT	11156
Fe-58	ENDF/B-VI.1	2637	FE058E6.DAT	7404
Co-59	END/B-VI.1	2725	CO059E6.DAT	7878
Ni-58	ENDF/B-VI.1	2825	NI058E6.DAT	9956
Ni-60	ENDF/B-VI.1	2831	NI060E6.DAT	6716
Ni-61	ENDF/B-VI.1	2834	NI061E6.DAT	6984
Ni-62	ENDF/B-VI.1	2837	NI062E6.DAT	5739
Ni-64	ENDF/B-VI.1	2843	NI064E6.DAT	5100
Cu-63	ENDF/B-VI.2	2925	CU063E6.DAT	9460
Cu-65	ENDF/B-VI.2	2931	CU065E6.DAT	7943
Ga-nat	JENDL-3.2	3100	GA000J3.DAT	8456
Zr-nat	JENDL-FF	4000	ZR000JFF.DAT	13145
Nb-93	JENDL-FF	4193	NB093JFF.DAT	6864
Mo-nat	JENDL-FF	4200	MO000JFF.DAT	18228
Sn-nat	BROND-2.1	5000	SN000BR.DAT	3633
Ta-181	JENDL-3.1	3731	TA181J3.DAT	4617
W-nat	JENDL-FF	7400	W000JFF.DAT	14345
Au-197	ENDF/B-VI.1	7925	AU197E6.DAT	1030
Pb-206	ENDF/B-VI.0	8231	PB206E6.DAT	8050
Pb-207	ENDF/B-VI.1	8234	PB207E6.DAT	8046
Pb-208	ENDF/B-VI.0	8237	PB208E6.DAT	5520
Bi-209	JENDL-3.1	3831	BI209J3.DAT	4227

Appendix B

List of FENDL/E-2.0 Evaluations for photon-atom interaction
taken from ENDF/B-VI photon-atom interaction library

MATERIAL	MAT No.	No. Records
AL000	1300	1610
B000	500	1277
BA000	5600	2311
BE000	400	883
BI000	8300	2836
C000	600	1198
CA000	2000	1629
CL000	1700	1599
CO000	2700	1904
CR000	2400	1838
CU000	2900	1737
F000	900	1263
FE000	2600	1845
H000	100	833
K000	1900	1635
LI000	300	911
MG000	1200	1309
MN000	2500	1882
MO000	4200	2118
N000	700	1292
NA000	1100	1368
NB000	4100	2184
NI000	2800	1870
O000	800	1207
P000	1500	1576
PB000	8200	2840
S000	1600	1573
SI000	1400	1607
SN000	5000	2327
TA000	7300	2652
TI000	2200	1882
V000	2300	1882
W000	7400	2668
ZR000	4000	2190

DISTRIBUTION OF THE FENDL2 LIBRARY

(As recommended at the IAEA Advisory Group Meeting on FENDL, held at IAEA Headquarters, Vienna, Austria, March 1997.)

The master copy of the FENDL-2 library resides with the Nuclear Data Section of the International Atomic Energy Agency. To facilitate user access to the library the official copy of FENDL-2 will be distributed in XXX to the major nuclear data centres in Europe (NEA Data Bank, Paris), Japan (JNDC, Tokai-mura), Russia (CJD, Obninsk) and USA (NNDC, Brookhaven and RSIC, Oak Ridge). As agreed between data centers, sharing common FENDL information, the recipients are receiving now the same products from all above centers. The data are available and may be further distributed to the user community according to the customer service options given below. Each FENDL sub-library will be in a single data set, i.e. Activation, Decay, etc. in the 8 mm tape, 6 mm tape, 4 mm tape or standard 9 track magnetic tape (6250 bpi or 1600 bpi) and CD-ROM options. The interested scientists may request FENDL-1 (or parts of it) directly from the IAEA/NDS or from one of these centers.

Table 1. FENDL CUSTOMER SERVICE OPTIONS

MEDIA	FORMAT	By WHOM
Electronic	FTP	IAEA, NEADB, NNDC
4 mm tape	UNIX TAR	CJD, IAEA, NEADB, NNDC, RSIC
	VAX BACKUP	CJD, IAEA, NEADB, NNDC
	ASCII	NEADB
6 mm tape	UNIX TAR	NEADB
	VAX BACKUP	NEADB
	ASCII	NEADB
8 mm tape	UNIX TAR	NEADB, NNDC, RSIC
	VAX BACKUP	NEADB, NNDC
	ASCII	NEADB
9 track	ASCII	CJD, IAEA
	EBCDIC	CJD, IAEA
CD-ROM	UNIX TAR	RSIC
	ASCII	NEADB

Table notes

- 1) NNDC will distribute FENDL unprocessed data
- 2) RSIC will distribute FENDL processed data
- 3) RSIC offers cost free service to ITER customers